III.4. FROST THRUST MEASUREMENTS ON PILES

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Upward thrust on foundation piling due to frost action has been a problem in the design, construction, and maintenance of structures throughout arctic, subarctic, and temperate regions. Seasonal freezing and thawing of the upper layers of ground cause differential movements which can be detrimental to a foundation. In pile foundations, the heaving of the ground during the freezing season imparts an upward thrust to the pile by adfreeze and the stability of a pile foundation is dependent upon the proper evaluation of this force with the other forces on the foundation.

During the past 15 years, considerable research has been conducted to establish design criteria for estimating the load capacity of piles in permafrost (References 1, 2, 3, 4, 5 and 6). The problem of frost thrust on piling has long been recognized and several methods have been used to cope with it. A rule of thumb for embedment of piles to a depth in permafrost equal to twice the expected depth of the active layer has been used to counteract the heave thrust (Reference 7). Investigations at Fairbanks, Alaska have indicated that a minimum embedment of 10 ft in permafrost is required to counteract heave thrust in the area (Reference 5). Oil-wax filled casings or sleeves, grease coatings, tar paper wraps, and treated backfill materials have also been used to reduce or eliminate pile heave thrust (Reference 8).

Although several measures have been investigated and used as anti-heave devices on foundation piling, very little information has been obtained on the actual magnitude of the frost thrust which creates this heave problem. This paper presents the results of a field test to measure the frost thrust on creosoted timber, and 8 in. steel pipe, piles. The test is one of a series of tests conducted by the U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL). A comprehensive report on the series is in preparation (Reference 9). The field data was obtained from a test installation at the Alaska Field Station (AFS) of CRREL at Fairbanks, Alaska.

TEST INSTALLATION

Site Conditions

The Alaska Field Station is located about 2.5 miles northeast of the city of Fairbanks, Alaska. Fairbanks has a continental climate, sheltered from maritime influences by various Alaskan mountain ranges. The mean annual temperature is 25.8°F with extremes of 93° to -66°F. The mean freezing and thawing indices are about 5300 and 3200 degree days, respectively. Average annual precipitation is about 12 in. of water and water equivalent including a mean annual snowfall of about 40 in.

The heave force measurements installation was installed in Pile Site B at AFS (Figure 1). This pile site, approximately 100 x 200 ft in size, was originally cleared of all trees, brush, and surface organic material in the spring of 1950. In the summer of 1952, 32 test piles were installed in the area and later tested in extraction and in load-settlement (Reference 1).

Soil conditions at the field station, in general, consist of organic and inorganic silts with peat layers to depths of 75 to 125 ft, with sands and gravels encountered below the silt and extending to schist bedrock at about 250 ft. Figure 2 shows the boring logs, water content, and dry unit weight of the material in the seasonal thaw zone at two locations at the test site of the test installation. Soil descriptions are in accordance with the method of describing and classifying frozen soils developed by CRREL and the National Research Council of Canada (References 10, 11 and 12).

Heave Force Measurement Devices

In the summer of 1962, two heave force test piles were installed in Pile Site B at AFS. The installation included restrained heave test piles of creosoted timber and 8 in. diameter steel pipe and also of identically installed but unrestrained (or dummy) piles, that were allowed to move upward with the heaving ground (Figure 3). The heave force test devices consisted of the test piles of creosoted timber and steel pipe and 25 ft anchor piles. The anchor piles were made from sections of 6WF25 steel sections and 8 in. steel pipe for the timber and pipe test piles respectively. The test piles extended to a depth of 6.5 ft, which at the time of installation was the assumed depth of the seasonal thaw layer, and the anchor piles extended 25 ft into permafrost directly below the test piles (Figure 3).

Four 1 in. steel rods extended through the full length of the test piles to transfer the heave thrust to the anchor piles. In the timber pile installation, the rods were welded to the anchor pile. In the pipe pile installation, the rods were held by nuts bearing on a 1 1/2 in. plate welded to the inside of the anchor pile. Proving rings were placed at the tops of the assemblies between two 1 1/2 in. thick plates, and the top plates were restrained by nuts on the 1 in. diameter rods. The joint between the 8 in. test pipe and anchor piles was sealed with a rubber gasket to prevent the entrance of ground water or slurry. Each assembly was pre-assembled and installed as a unit into 18 in. diameter dry augered holes and backfilled with silt slurry.

Instrumentation

To record ground temperature and the advance of freeze and thaw through the seasonal thaw zone, thermocouple assemblies were attached to each test and dummy pile; the thermocouples were spaced at 6 in. intervals from the ground surface to a depth of 6.0 ft. Additional assemblies were fastened to, and installed with, the anchor piles, with thermocouples located at 6.0, 8.0, 10.0, 15.0, 20.0, 25.0 and 31.0 ft depths.

Vertical movements of each test and dummy pile were monitored by three extensometer-type dial gauges mounted on instrumentation beams (Figure 3) and positioned 120 degrees apart around the pile. The instrumentation beams were supported by 4.5 in. diameter pipe piles driven to approximately 11 ft below the ground surface with 7 in. diameter pipe used as casing through the active layer. The annular space between the casing and piles was filled with oil to prevent heaving of the instrumentation supports.

Proving rings were installed above each test pile to record the heave thrust during the freezing season. A 60,000 lb capacity proving ring was used in the pipe pile installation and a 50,000 lb capacity ring in the timber pile installation. Both proving rings were protected by an insulated enclosure, heated with two thermostatically controlled 100 watt electric light bulbs to maintain the temperature at 65°F (Figure 4).

The entire test area was protected by a wood frame shelter to facilitate maximum frost penetration by preventing the accumulation of snow and to shield the instrumentation from sunlight and snowfall which could cause deflections of the instrumentation beams.

TEST PROCEDURE AND RESULTS

Ground and Air Temperatures

All thermocouple assemblies were observed two or three times weekly from the last week of October 1962 through June 1963. Temperatures were recorded with a portable precision millivolt potentiometer having an ice bath reference junction. The ground temperature isotherms for each heave test pile, based on temperature observations from the test pile assemblies, are plotted on Figures 5 and 6, which are composite plots of the results of the two test installations. The depth to permafrost was assumed to be approximately 6.5 ft. The 32°F isotherm did not penetrate to that depth until mid-February at the pipe pile and late February at the timber pile. The slight difference in penetration could be because steel is a better conductor of heat than timber and cold air would naturally flow to the bottom of the pipe pile.

Daily air temperature observations were made at the test site and the mean air temperatures are plotted on Figures 5 and 6. The mean air temperature dropped below 32°F in mid October and remained below 32°F until mid April. The temperature fluctuated greatly during the winter and the lowest temperatures were observed in early January. The average air temperatures in January were the warmest in 26 years.

Vertical Movements

Vertical movement observations were made on both test piles twice daily throughout the freezing season. Continuous plots of the vertical movement of each pile are shown on Figures 5 and 6. Vertical movement of the dummy piles increased during the freezeback of the seasonal thaw zone and then continued slightly after complete freezeback. Total heave amounted to 4.10 in. and 4.15 in. for the steel and timber dummy piles, respectively. Vertical movement of the test piles, restrained by the proving rings and reaction devices, was a maximum of 0.7 inches for the steel pile and 0.3 inches for the timber pile.

Heave Force Measurements

Proving ring readings were made twice daily at approximately the same time each morning and afternoon from the start of the freezing season until June 1963. The averges of the daily heave force measurements are plotted on Figures 5 and 6. The measurable heave force started after the 32°F isotherm had penetrated approximately 12 in. The maximum heave force occurred when the 32°F isotherm had penetrated between 90 and 100% of the seasonal thaw zone and then fluctuated throughout the remainder of the winter in response to the fluctuation of air (ground) temperatures.

DISCUSSION OF RESULTS

The results indicate a slight lag between the penetration of the 32°F isotherm and the start of measurable pile heave force. Factors causing this slight lag could be the weakness of the adfreeze bond during the initial freezeback of the ground surface, the frictional resistance of the unfrozen soil beneath the frost, and the freezing point depression. Because of this freezing point depression and the error factor in thermocouple observations, the actual frost line penetration probably lags behind the penetration of the 32°F isotherm.

Heave of the dummy piles and the heave force increased considerably during the freezeback of the seasonal thaw layer. Gradual heave of the dummy piles continued throughout the winter until surface thawing started in the spring. The area surrounding the test site had an undisturbed snow cover in contrast to the sheltered area at the test piles and would have a shallow frost penetration. This gradual heaving throughout the winter is attributed to ice lenses formed by the migration of water from the surrounding soil. Heaving throughout the winter, at a diminishing rate, would also occur in non-permafrost areas or areas having a deep active layer where complete freezeback does not occur each year.

Maximum heave forces of 55,800 lb for the steel pipe and 35,600 lb for the creosoted timber pile occurred when freezeback of the active layer was between 90 and 100% complete. During the remainder of the winter season, distinct fluctuations in heave force were observed. The peaks or maximum points of these fluctuations occurred shortly after a decrease in air and ground temperature.

The low points appeared just after warming trends in the air temperature and had a distinct time lag with depth, as observed during the cooling periods. Similar fluctuations have been observed by Japanese investigators (Reference 13) and the decrease in heave force was inferred to be a relaxation phenomenon. The rate of advance of the freezing front would be lower during the warmer periods and heave force decreases when soil heave decreases. During periods of higher surface temperatures, the relaxation rate of the soil immediately surrounding the pile might exceed the heave rate and the frost thrust could be reduced.

Creep of the anchor piles is a factor in the decrease in heave force. Permafrost temperatures along the entire length of the anchor piles were relatively high and marginal (31.0 - 31.5°F). At these high temperatures, it is considered possible for progressive movement of the anchor piles to occur especially under the high loads indicated on the proving rings. A load of 55,000 lbs on the 8 in. pipe pile installation represents an average unit stress of approximately 7 psi on the 25 ft anchor pile. Pile investigations conducted in permafrost indicate movements could occur under such temperature and load conditions (Reference 5). Movement of the anchor piles is indicated by the fact that there was permanent movement of both test piles at the end of the test. Had no creep of the anchor piles occurred, all of the vertical movement should have been produced solely by the deflection of the proving rings and the elastic elongation of the steel rods and piles, i.e., 0.04 in. for a 10,000 lb load. The fact that approximately 0.5 in. of permanent movement of the steel pipe pile and 0.2 in. movement of the timber pile remained at the end of the test indicated that some movement of the anchor piles had occurred during the tests.

CONCLUSIONS

The results of this field investigation indicate that heaving forces generated on piling of the sizes and types tested during the seasonal freezing of the frost susceptible soils may reach or even surpass 50,000 lb for these movements. Under normal field conditions, such uplift forces could exceed the sum of the ultimate anchoring capacity of the permafrost embedment and the imposed pile load, resulting in an upward annual displacement. Maximum rate of heave occurs during the early winter months, at relatively shallow depths, and the maximum heave force on piling occurs during periods of active frost penetration with very cold near-surface ground temperatures. Maximum or near maximum heave forces can be produced at relatively shallow depths (3 ft) or at greater depths (more than 6 ft) under these conditions.

Although this investigation was conducted in a permafrost area, it may be assumed that heave forces in the same order of magnitude can be produced in temperate regions because of frost action under similar soil and moisture conditions near the ground surface. Based on the larger heave force registered on the pipe piles, it is concluded that the effective unit adfreeze bond of the active layer is dependent on surface conditions as well as on surface area. Maximum average unit adfreeze (tangential) stress developed on the steel pipe pile (Figure 7) was approximately 41 psi as opposed to 12 psi on the creosoted timber pile. Similar conclusions have been reached in pile load settlement tests conducted in permafrost (Reference 5).

Based on the results of this field investigation and preliminary laboratory studies conducted in the cold rooms, an investigation is now being made using similar field installations to investigate the effectiveness of various pile surface and backfill treatments in reducing the heave thrust on piles and powerpoles. Preliminary results indicate that it may be possible to reduce the heave thrust to tolerable magnitudes without completely insulating the top 4 to 6 ft of the pile with casings or sleeves, a procedure that reduces the lateral stability of the pile.

ACKNOWLEDGMENTS

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Discussion

J.A. Ellwood asked how the piles are isolated from the soil to reduce movements. The author replied that CRREL is experimenting with surface treatments and backfilling with treated materials. Coatings, applied by brush or spraying, which include epoxy and enamel paint, have reduced the adfreezing bond by as much as 20 percent.

C.A. Noble asked for information on the magnitude of movement in the anchor pile system. Reed replied that the total movement under 55,000 lbs. of load was about 2/10 inch. Because of creep action of the anchor pile system, this might not be the maximum movement. In earlier tests the maximum forces were 25,000 lbs - half of the present test.

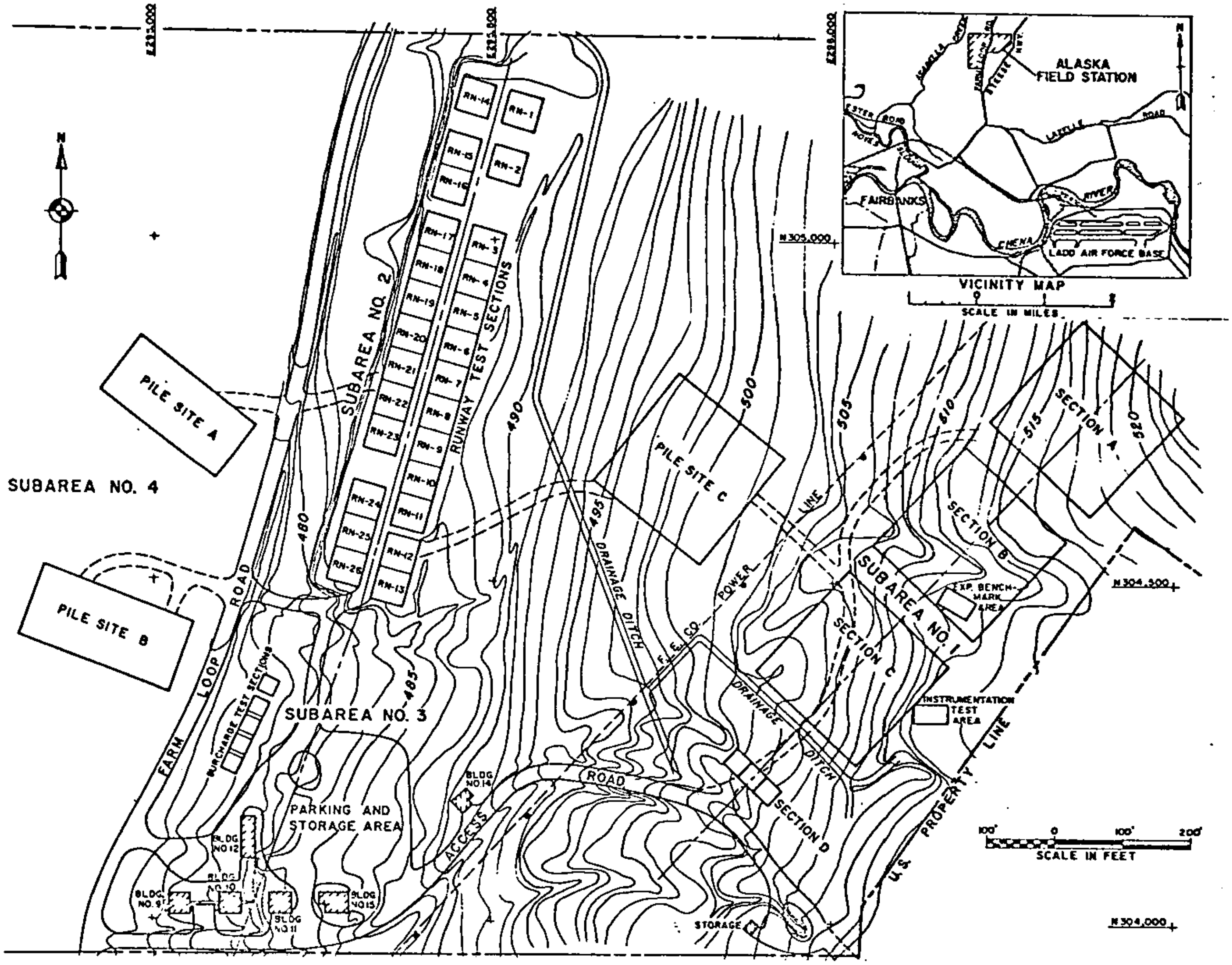

FIGURE 1 PLAN OF ALASKA FIELD STATION

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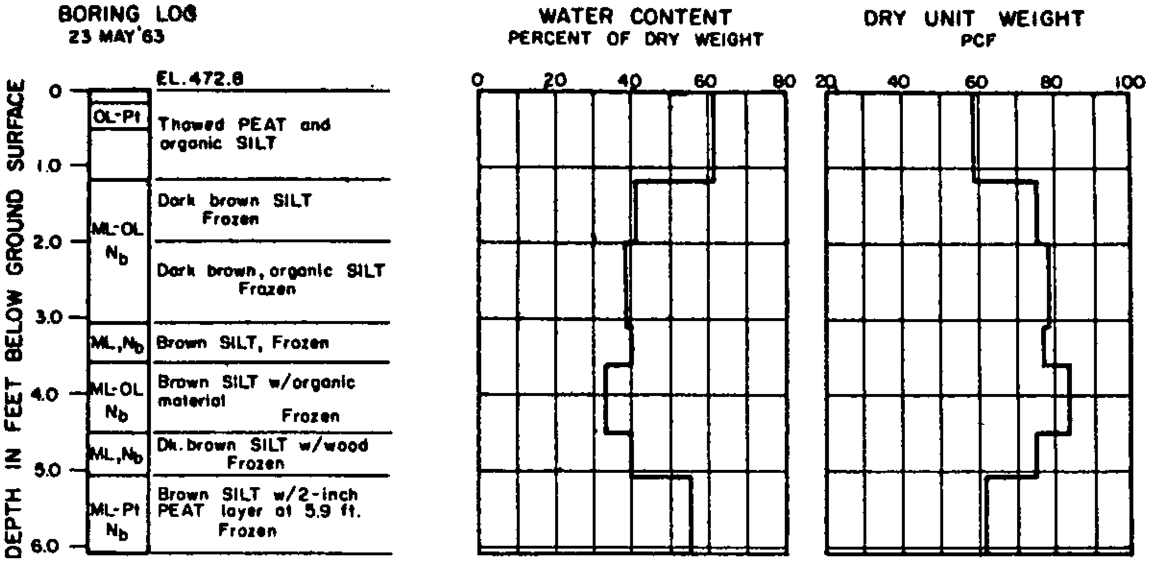
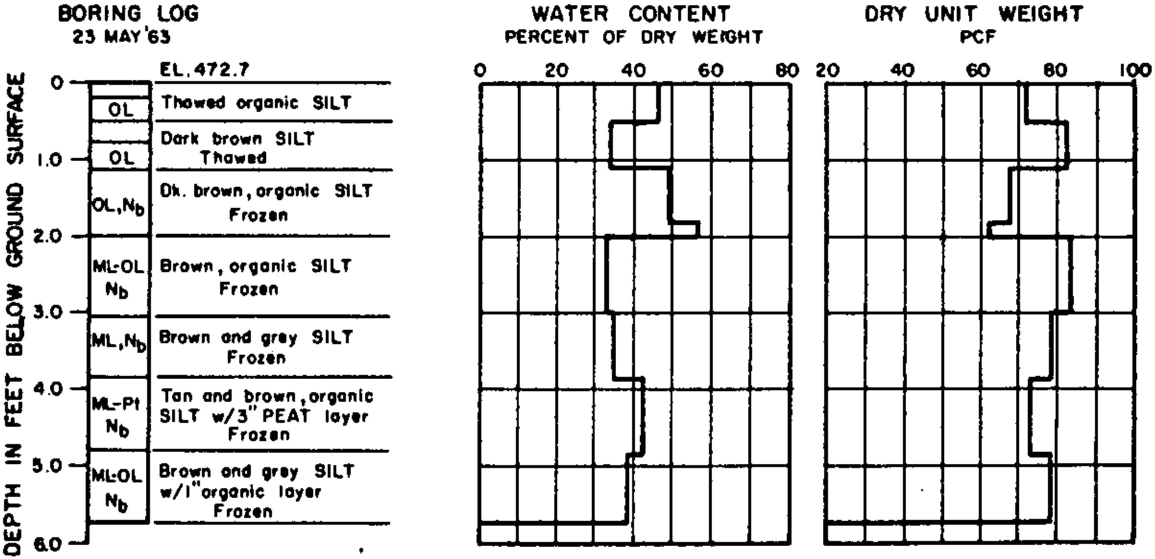


0 to 1'-2", Thawed soil. (Sampled with Hvorslev Sampler)
1'-2" to 6'-1", Frozen active layer. (Sampled by driving $1\frac{1}{2}$" Shelby Tube w/Jack Hammer)

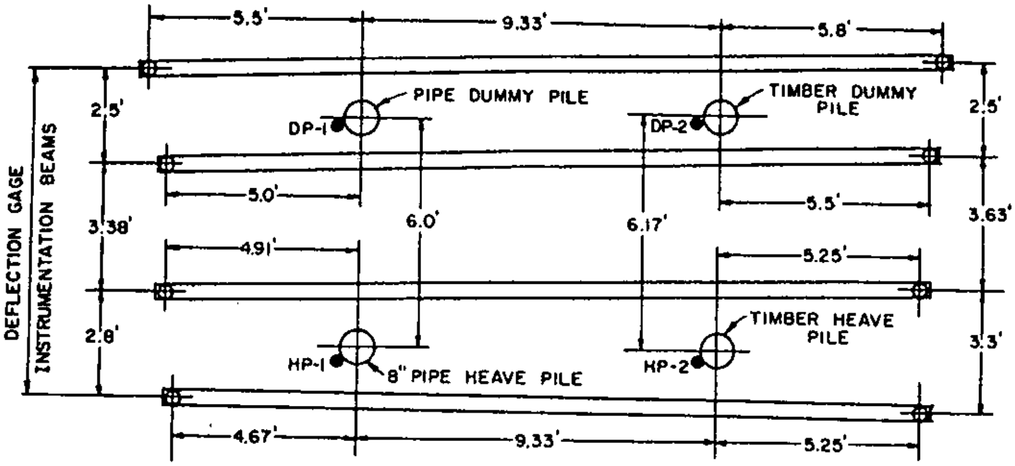
a. SOILS EXPLORATION MIDWAY BETWEEN 8" PIPE TEST AND DUMMY PILES



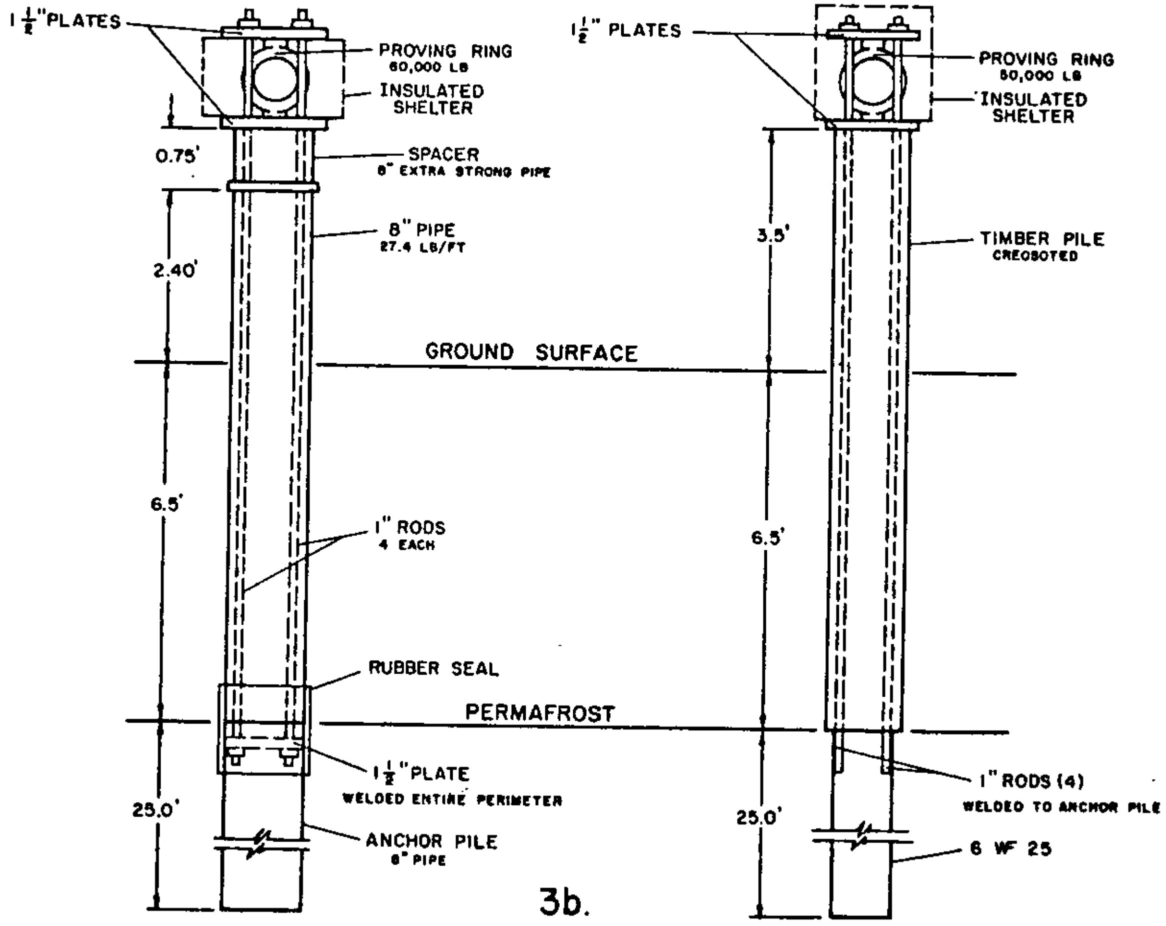
Sampled by driving $1\frac{1}{2}$" Shelby Tube w/Jack Hammer.

b. SOILS EXPLORATION MIDWAY BETWEEN TIMBER TEST AND DUMMY PILES

FIGURE 2 BORING LOGS AND SOIL DATA



3a.



3b.

FIGURE 3

PLAN AND ELEVATION VIEW OF TEST INSTALLATION

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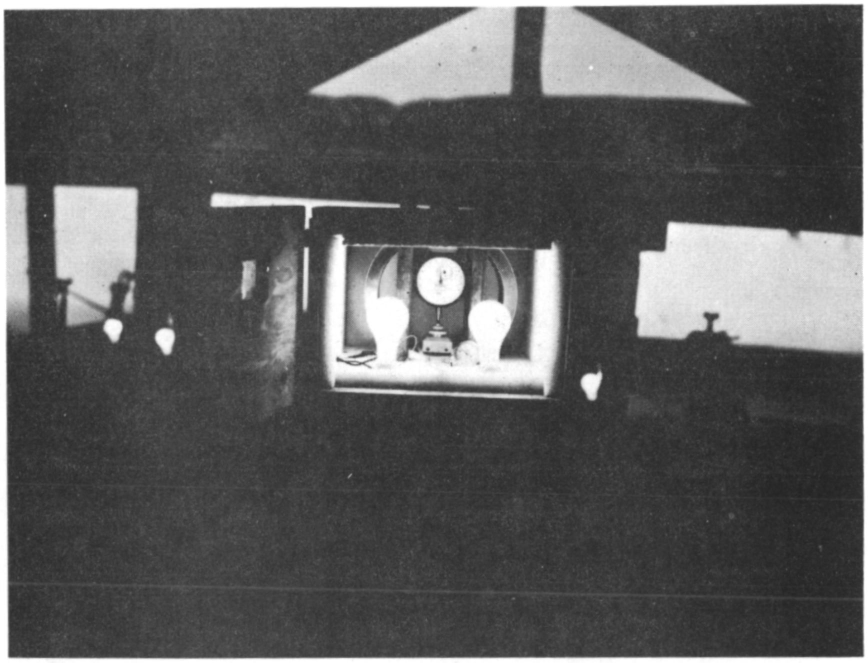

FIGURE 4

VIEW OF INSULATED ENCLOSURE AROUND PROVING RING

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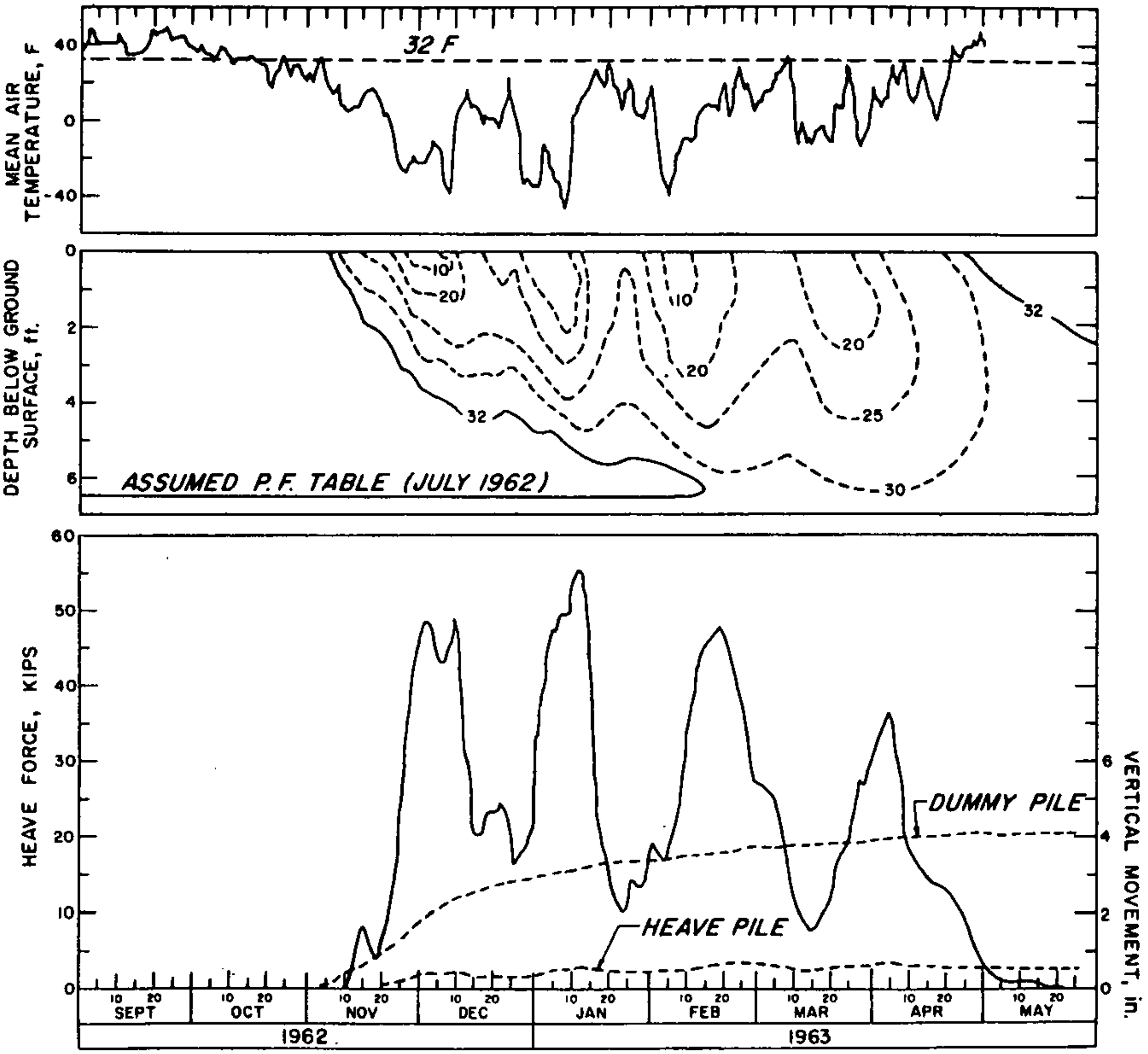

FIGURE 5 TEST OBSERVATIONS - 8" STEEL PIPE PILE

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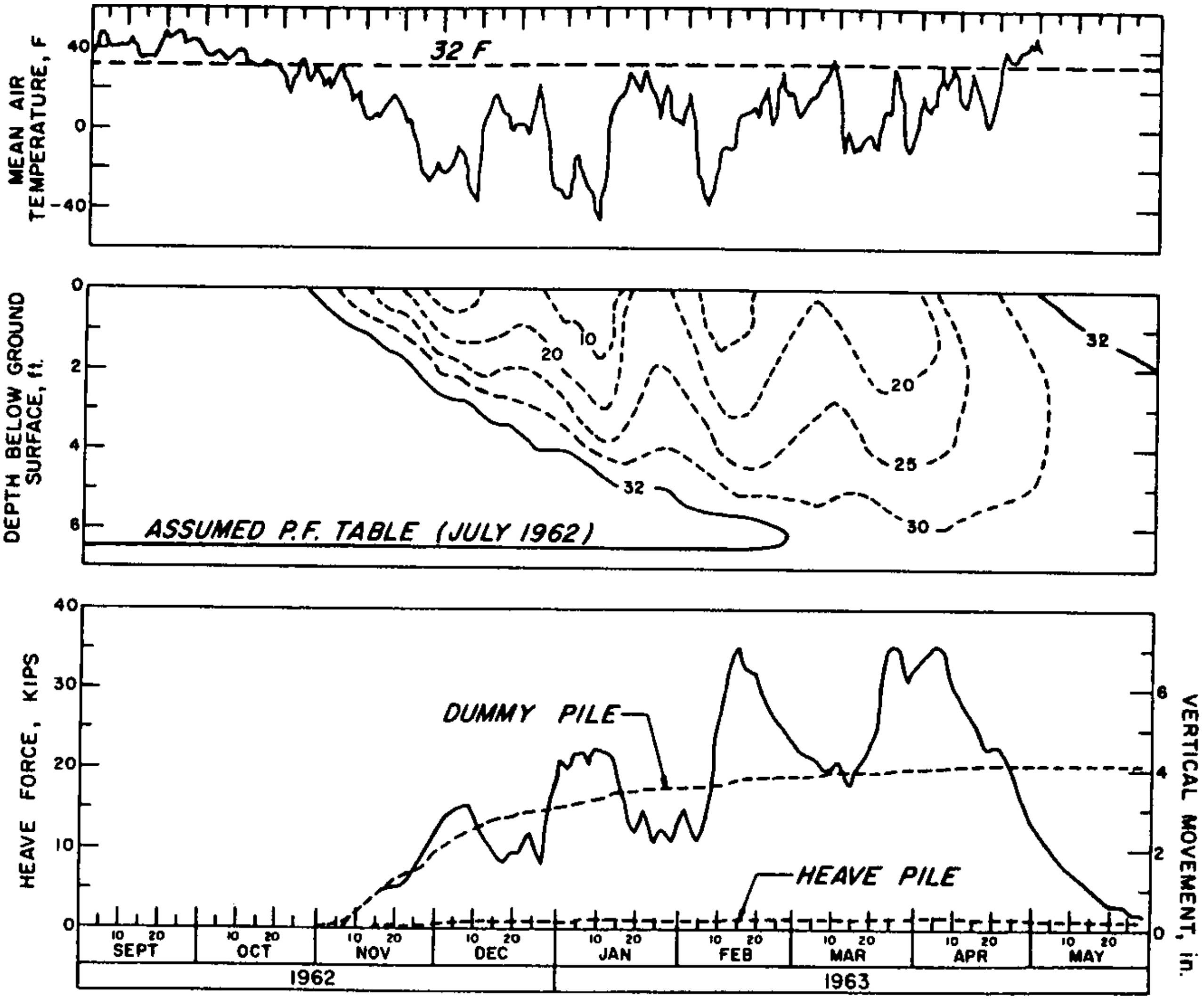

FIGURE 6 TEST OBSERVATIONS - CREOSOTED TIMBER PILE

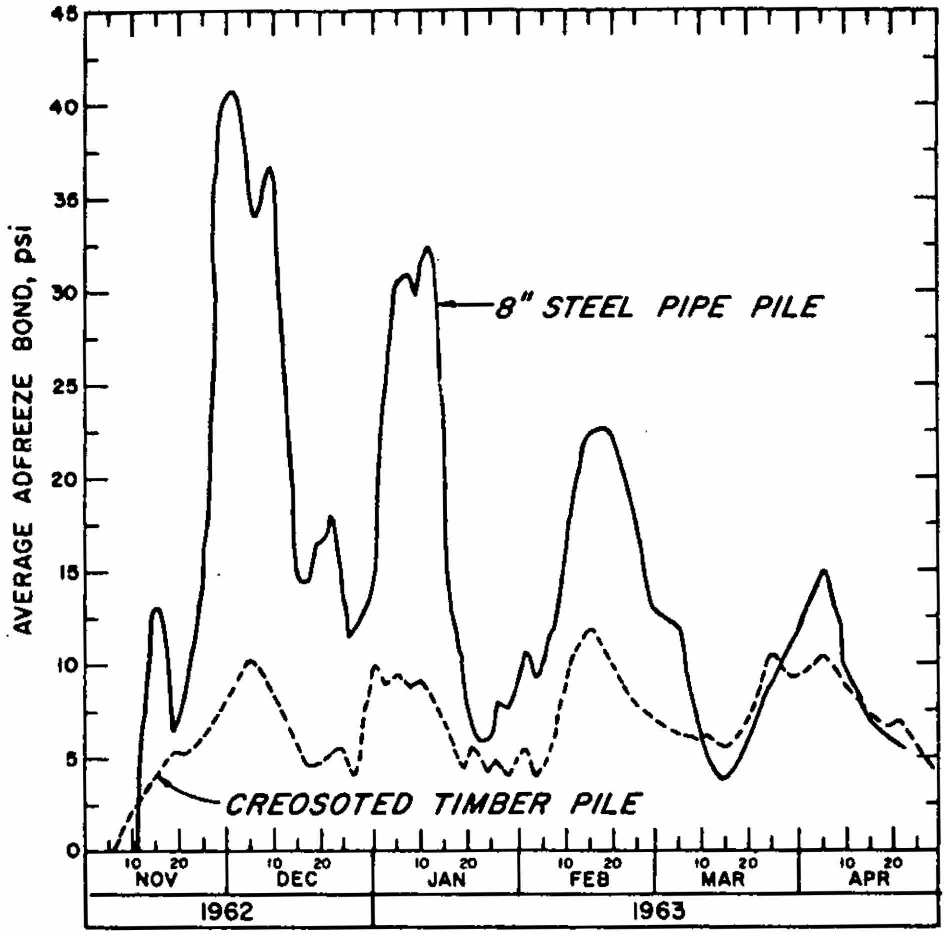

FIGURE 7

AVERAGE ADFREEZE BOND STRESS VS TIME